CONTRIBUTION TO THE PROBLEM OF OCULOGRAVIC ILLUSION

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Disturbances of the oculomotor function during weightlessness, and also during the effect of small g-forces, when hemodynamic disturbances have not yet come into the foreground, are the most noticeable subjectively. These disturbances may lead to a considerable deterioration of one operator's capability of monitoring visual reference points under such conditions, because of the creation of the illusion that they are shifting. Not accidentally, reactions of the oculomotor system were commented on in the very first papers devoted to the study of the effect of variations in weight on the human being.

On the basis of theoretical calculations a number of authors have reached the conclusion that in the transition from normal gravity to weightlessness the sensation of falling arises as well as seeming displacement in the visual field in the "downward" direction. These illusions have been called "oculogravic."

In explaining these phenomena authors have based themselves on the tonic effect of vestibular apparatuses on the eye musculature.

The significance of tonic changes of the oculomotor system in the generation of oculogravic illusions is confirmed by observations of a persistent image as gravity changes. In weightlessness the persistent image seems to be shifted upward and during gravitational acceleration downward. /176

Objective proof that the eyeball rolls under such conditions was first obtained by Yuganov and his colleagues in experiments with rabbits during rocket and aircraft flights. The data they obtained permitted them to put forward the idea that the displacement of a persistent visual image, as observed by man when gravity changes, is caused by rolling of the eye as a result of the tonic vestibular effect.

A somewhat different modification of our experiments made it possible not only to determine the position of a persistent image and of a visual target during changes in weight, but also to observe their mutual displacement.

METHOD

The state of weightlessness was produced in the cabin of an aircraft flying along a parabolic trajectory. The activity of each period of weightlessness, 25-30 sec, was preceded and followed by gravitational aeculeration (2 g's; 15-18 sec).

An adaptometer (ADM) was used in the investigations. Three series of experiments were carried out. In the first series the test subjects were exposed to a visual reference point (a cross) during the entire experiment. In the second series the visual reference point was presented to the test subject in horizontal

flight and was turned off 10 sec before the beginning of the first stress period, following which the test subject had to follow the resultant persistent image in total darkness throughout the experiment. In the third series the cross was illuminated in front of the test subject during horizontal flight; 10 sec before the first g-force set in it was turned off, and the test subject tracked the persistent image. In some experiments the luminous reference point was again turned on at the tenth second of weightlessness and in others at the seventh second of gravitational acceleration; the test subject was required to look at the center of the image.

The ADM adaptometer prevented the luminous pattern from moving relative to the head of the test subject; the luminous reference point was located 25 cm from the eyes. In order to evaluate the angular characteristics of the visual field, luminous reference points within the adaptometer were used: the outlines of the cross (located at five angular degrees from the center of the cross) and a luminous point lying 12 angular degress above the center of the cross. The brightness of the visual reference point equalled 22 apostilbs.

Four people participated in the experiments; two had no reactions whatever during weightlessness, and two had pronounced psychic reactions (a sense of fear, a falling sensation) when in the state of weightlessness for the first few times.

RESULTS /177

All the test subjects observed similar phenomena during the experiments. The continuously exposed visual reference point seemed to shift downward during weightlessness and upward during gravitational acceleration. In the absence of a visual reference point the persistent image, on the contrary, shifted upward during weightlessness and downward during acceleration (Fig. 1). In those cases when the cross was illuminated during weightlessness, it was found to be located below the persistent image. But when the test subjects focused their attention on the lighted reference point, the persistent image began to fall and came into line with the illuminated cross. Two test subjects noted, in addition, that they had the feeling "as if the persistent image caught up with the visual reference point, while the latter slipped away downward." The opposite phenomena were noted during gravitational acceleration: when turned on the cross proved to be above the persistent image, and the persistent image began to rise and come into line with the illuminated cross. Both the test subjects who had sensations of fear and falling during their first exposures to weightlessness reported that the distance between the centers of the persistent image and the illuminated cross was somewhat greater than 12°; in the opinion of the others it did not exceed 5°.

Besides the above-mentioned phenomena, one test subject noted that at the instant of transition from acceleration to weightlessness, the visual reference point, when it was continuously presented throughout the experiment, "leaped upward, and only then moved downward."

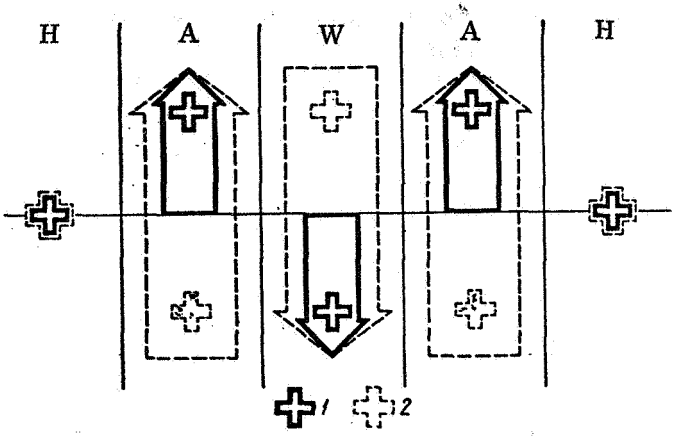

Figure 1. Diagram of the Shift of the Visual Reference Point (1) and of the Persistent Image (2) During Weightlessness (W), Acceleration (A) and Horizontal Flight (H) With Natural Gravity.

The Solid Line Represents the Position of the Reference Point and the Broken Line that of the Image; the Arrow Indicates Shift of the Image (or reference point).

DISCUSSION /178

On the basis of the cited work it is possible to say with confidence that in weightlessness the forward pole of the eye shifts "upward" in man and animals and shifts "downward" in the case of gravitational acceleration, as a result of tonic reaction from the gravireceptors on the oculomotor musculature. Apparent shifts of a persistent image occur when the eyeball rolls. Up to the present time, however, no specific conclusions whatever have been drawn as to nature of the illusory motion of the visual reference points "downward during weightlessness and upward during acceleration, i.e., us to oculogravic illusion. The opinion that it may be caused by displacement of the eyeball as a result of the above-described tonic reaction does not withstand criticism, since in such a case the point of optical focus would have shifted and the visual reference point would have displaced from the center of the field of vision, which is not observed in reality. In the discussion of these phenomena in Graybill's papers, no more was said than that the aculogravic illusion is not connected with the phenomena of nystagmus.

On the basis of the results of our investigations as well as of analyzing the work of other authors, the mechanism of these illusions may be represented as follows. According to the reports of the test subjects, the illuminated reference point, when turned on during weightlessness, proves to be located below the persistent image. Efforts to focus attention on the reference point caused the persistent image to drop until it coincided with the visual reference point. This indicates that the forward pole of the eye, shifted upwards as a result of the tonic effect of gravireceptors during weightlessness, drops as a result of volitional effort, i.e., efferent cortical signals. Downward rolling of the eyeball by the

forward pole is governed, apparently, by the additional force of the inferior rectus of the eye. Simultaneously with this action the visible object seemed, according to the reports of the test subjects, to be displaced downward "slipping away from the persistent image," i.e., the optically perceived space in front of the test subjects moved downward. This, of course, could not have been caused by motion of the visual image over the retina; in our opinion, it is incident to the "displacement" of the cortical image of the optically perceived ambient space, the reasons for which may be, first, the effect of inverse afferentation from the proprioceptors of the inferior rectus of the eye, reflecting its supplementary force, and second, the direct effect of afferentation, change under the conditions of weightlessness, from the gravireceptors on the optical centers of the cortex.

Evidence for the direct effect of information from the gravireceptors, changed during weightlessness, on the higher nervous centers is provided by the fact that the action of this information causes not only apparent uniform dislocation of the visual reference points, but also, as demonstrated by our experiments, illusory distortion of their shape. The distortion occurs because elements of the visual pattern upon which attention is focused remain fixed while the elements located to the side of the focus point shift. This phenomenon cannot be explained only as a result of a change in inverse afferentation from the oculomotor system or as a result of nystagmus; without doubt it is a result of disturbance of the central integrative functions of vision. It must be noted that vertical nystagmus may occur in man because of the effect of the cancellation of gravity and may play a certain part in the genesis of optical illusions. Evidence of the presence of nystagmus during weightlessness is provided by the reports of the test subjects that visual objects "flicker" during weightlessness, and also by the nystagmoid vibration of the eyeballs during weightlessness which we observed in individual test subjects. /179

Testifying to the significance of the central nervous system in organizing optical illusions is the fact that in our investigations as well as in those of other authors the oculogravic illusions were subjectively noticeable only in darkness, and in this case damping develops in the cortex of the cerebral hemispheres, i.e., its regulating function is weakened.

The character of the eyeball motion which compensates the gravireceptor tonic reaction depends on the shape of the visual reference point, in particular, on the presence of a focal point in the field of vision. A proof of this are the interesting facts obtained by Yuganov and others in flights in which short-term weightlessness was produced (28-30 sec). A tendency was observed to shift the center of the pupil upward in the case of g-loading and in the opposite sense to the level of horizontal flight or even lower in the case of weightlessness.

In our opinion these data indicate that the compensatory force of the inferior eye muscles counteracting the gravireceptor tonic reaction may be superfluous. Such "overregulation" occurred because the visible reference point was not fixed in view at the time of its illusory displacement of the ambient space during a change in gravity.

The intensity of the oculogravic illusions depended to a significant degree on the individual peculiarities of the test subjects. According to our data they were more pronounced in people who experienced a strong sense of fear and falling in their first acquaintance with weightlessness. In comparing Yuganov's data with

the results of our examination, during weightlessness, of the test subjects who participated in his tests, it was found that strong dislocations of the pupil during a change in gravity occurred in people who had more pronounced psychic reactions on the occasion of their first exposure to weightlessness.

Without examining in greater detail in this section the mechanisms by which vision is disturbed during changes in gravity, let us recall the work of Shone who, on the basis of his investigations using a centrifuge, asserts that the magnitude of vertical displacement in the case of oculogravic illusion does not depend on the pressure exerted by the otolith organs of the utriculi on maculae. According to his data, the magnitude of the displacement is found to be in correlational agreement with the degree of slope of the tiny sensitive hairs of the otoliths. /180

Thus, the data of the present investigation, as well as the studies of other authors, make it possible to assume that oculogravic illusion in weightlessness occurs under the effect of inverse afferentation, signaling changes in the oculomotor system, the changes compensating the tonic effect of gravireceptors on the system. During weightlessness an oculomotor reaction (with a downward displacement of the pupils) is possible which is opposite to the reaction from the gravireceptors that arises under such conditions; the motion of the eyes, with downward displacement of the pupils, is a consequence of excessive compensation of the gravireceptor tonic reaction. More pronounced oculogravic illusions occur in people who have a tendency to psychic reactions under these conditions (sense of falling, of fear).